JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 18 2010

FLOOD ROUTING IN THE OGUNPA RIVER IN NIGERIA USING HEC-RAS

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The HEC-RAS (Hydrologic Engineering Center - River Analysis System) modeling framework was used to evaluate both the flood routing and water flow activity of the Ogunpa River, one of the largest rivers running through Oyo state, Nigeria, situated in the densely-populated town of Ibadan. The river is significantly affected by its urban location, with the majority of its annual flood events resulting from direct human activity and urban interference. The river channel is the depository for an alarming amount of sewage, domestic, hospital and industrial wastes. The poor waste disposal habits within Ibadan are directly linked to the frequent flooding of the river, especially at downstream reaches. A single data entry of river channel geometry and flow into the HEC-RAS computer program is sufficient to model steady flow, unsteady flow, water surface profiles, sediment transport/movable boundary computations, and water quality. This study focused on the modeling of the steady flow water surface profile and the following results were obtained: the discharge of the 50 yr profile was 1.87 m^3/s while that of the 100-year profile was 2.8 m^3/s. The discharge was roughly constant between the distances of 1.21 - 2.02 km along the channel. The discharge was directly proportional to the stream length (between 7.9 km and 11 km). The volume of the 50-year profile was 3.76 x 105 m^3 while that of the 100-year profile was 4.82 x 105 m^3 in the lower course of the Ogunpa River. The difference between the 50-year and 100-year profiles results confirmed the urbanization in this region, which leads to increases in runoff and chemical and waste pollution. The channel velocity in the lower course tends to zero, which is a result of the stagnant nature of the river in the lower course due to the accumulation of heavy refuse. This particular region of the river channel is susceptible to flooding during peak rainfalls.

INTRODUCTION

Background

The Ogunpa is a major river running through the Ibadan metropolis, which is the capital of Oyo and the third largest city in Nigeria. It is a major outlet for other sub basins of the watershed. Ibadan city is highly urbanized and the land has been institutionalized for the development of residential development, industries, recreational grounds and educational establishments. Due to Ibadan's increasing population, land demand is an acute problem with residents using every available space along or on the banks of the Ogunpa River for personal use. This urbanization pressure is expected to lead to increased runoff of chemical and waste pollution (Sangodoyin, et al. 2002).

The intensity of damage caused by flooding of the river varies year to year. However, severe flooding of the Ogunpa River on August 31, 1980 destroyed life and property worth millions of dollars, thus making the Ogunpa a central topic of concern for both the residents of Ibadan and the Government of Nigeria. Before the August flood, occupants around the river went about their social-economic activities without considering the consequences of their actions. The combined effects of urbanization, improper waste management, and property-damaging floods have drawn national and international attention to this river and the capital city of Ibadan.

Flood routing is used to simulate flood wave movement through river reaches and reservoirs. Routing can be applied using either hydrologic or hydraulic approaches. In a hydrologic approach, the spatially lumped form of the continuity equation is applied, a water budget (or water balance) is determined, and the flux relation of inflow, and outflow is evaluated (Singh, 2004). Hydraulic approaches require both continuity and dynamic equations, which requires mass and momentum conservation, channel geometry (cross section shape, bed slope, etc.), and resistance characteristics such as river bed, banks, and floodplains (HEC-RAS, 2006).

Previous studies show the use of emerging technologies in flood routing which have received considerable attention in the hydrologic and hydraulic modeling field such as Fuzzy Logic (Xiong, et al. 2001), Artificial Neural Networks (Liong, et al. 2002), and Genetic Algorithms (Chau, 2006). Another method, HEC-RAS, has been one of the most widely used methods. It is capable of generating a large range of hydrologic responses from the river system with only a single entry of river geometry and flow data. The HEC-RAS model is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. It is based upon the principle of continuity as well as the hydraulic equations of St. Venant.

Models of flood routing can be broadly classified into hydrologic and hydraulic models. Hydrologic models are based on a spatially lumped form of the continuity equation, often called water budget or balance, which is a flux relation which expresses storage as a function of inflow and outflow. Combining these two equations leads to a first order ordinary differential equation (Singh, 1988). There are many other computer based programs for hydraulic and hydrologic modeling developed by the engineering community. Programs can be grouped into the following categories as reported by Oliver et al., (2004): single-event rainfall-runoff and routing models, flood hydraulics, continuous-stream-flow simulation models, and water-quality models. In studying the Ogunpa River, HEC-RAS was used because a single data entry of river channel geometry and flow is sufficient to model steady flow water surface profiles, unsteady flow, sediment transport/ movable boundary computations, and water quality analysis. Additional information is not available for the Ogunpa river, the use of HEC-RAS was deemed particularly suitable. The main objective of this study was to determine the water elevation profile of Ogunpa River using the HEC-RAS model.

Study Site

The Ogunpa River is located in Ibadan at a latitude of $3^o35'$and $4^o10'$N and a longitude of $7^o2'$ and $7^o4'$E. Ibadan is the capital of Oyo State, Nigeria, in West Africa (Figure 1). It is 128 km north of Lagos and 345 km south west of Abuja, the federal capital. When it is measured from the general post office in the central business district to the city boundary on the Ibadan-Lagos express way, the city radius is 12 to 15 km along the primary roads. The city's metropolitan region covers about 4200 km^2 with boundaries varying from 17 km in the south east to 44 km in the north east.

The city is spread over the strongly undulating plains and the quartzite hills and ridges of the Ogunpa River basin. This location is characterized by moderately steep gradient hills, numerous drainage lines and soil that range from generally light sandy loam to sandy clay-loam. These soils give the area a high potential for runoff generation and sediment yields (Areola et al, 1980).

Flooding in the Ogunpa River

The Ogunpa River takes its source from the Ashi village in the Orita Basorun area of Ibadan. The Ogunpa continues to channel through this highly-populated area of the city, despite the industrial, commercial, and residential development that surrounds it. Ogunpa river flooding occurs in the flat or low-lying terrain of Ibadan city where little or no provision has been made for surface drainage. Municipal waste refuse and eroded soil sediments contribute to the lower course stagnation of the river, resulting in poor drainage and a propensity for flooding (Table 1).

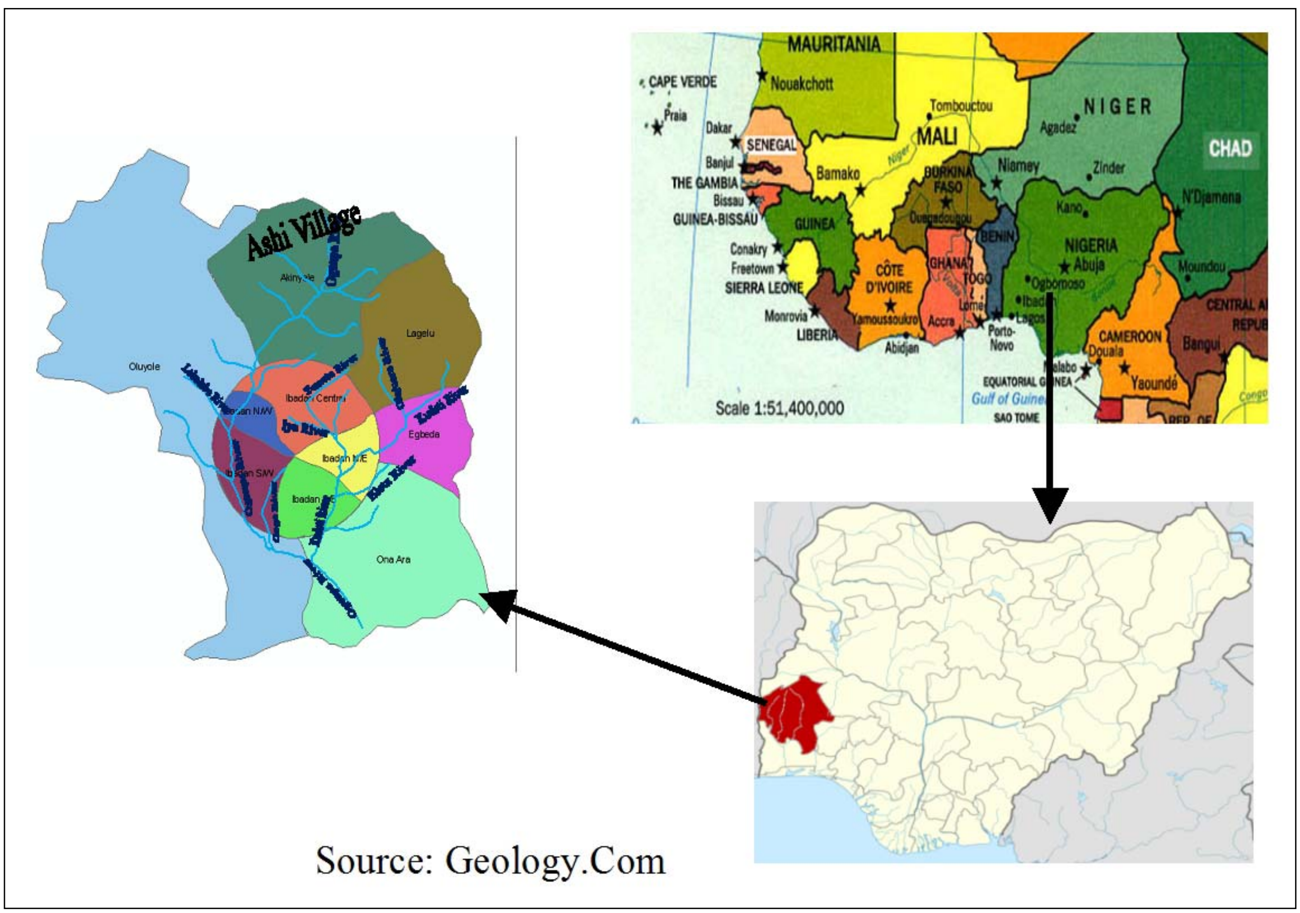

Figure 1. Study area map.

Table 1. Population and solid waste generation in Ibadan.

Year	Population ($x 10^3$)	Waste Generation per Year ($x 10^3$ tons)
1992	3430	751
1994	3620	754
1996	3638	797
1998	3748	821
2000	3860	845

Source: Haskoning and Konsadem Associates (2002).

The Ogunpa River disaster in 1980 claimed over 200 lives and caused millions of dollars worth of property damage within Ibadan. Although this was a more drastic occurrence, urban flooding has been a common phenomenon for decades. Bank overflow of the Ogunpa and Kudeti River was first experienced in the year 1955. The urbanization of Ibadan began around 1955, the same time that the bank of the Ogunpa and Kudeti Rivers both experienced flooding. The city experienced similar flooding disasters in 1960, 1961, 1963, and 1969. In 1978, the Nigerian government initiated a project to solve the flooding of the river, which was called the "Ogunpa River Channelization" project.

The causes of these floods were the compilation of municipal waste on the course of the river and the heavy downpour of rain in this part of Nigeria. Since around 1980, flash flooding has become an annual event, affecting various areas of the city along the course of the Ogunpa River and increasing the number of flood zones.

The tributaries play a major role in the flood event of the Ogunpa River; most of these tributaries are streams while some are domestic drainage directed towards the Ogunpa River. The dumping of domestic waste and refuse contributes to the poor color, taste and odor of the water. These tributaries are located within close proximity of domestic activities and have been degraded into near toxic depositories for both solid and liquid wastes. Over time, the accumulation of refuse has created a situation in which river and rainfall runoff is blocked, which has resulted in an increase in the head of the water profile above its bank.

METHODOLOGY

The flow and channel geometry needed to route the Ogunpa River was collected with permission from Osot Associates Consulting Engineers, a local consulting firm that was awarded a federal contract for the channelization of the Ogunpa River (Government of Nigeria Project). The river system schematic was developed based on the draft of survey undertaken by Sangodoyin, in 1996. Each step of the flow chart is described in detail later in the paper.

River System Schematic

Ogunpa River system was drawn on a reach-by-reach basis using the tools of HEC-RAS (Figure 2).

River reaches were drawn upstream to downstream in a positive flow direction using multi-segmented lines. Each reach is identified by a river name (i.e. stream name) and reach name (i.e. an additional qualifier). Reaches are drawn as multi-segmented lines. Each reach moves two points

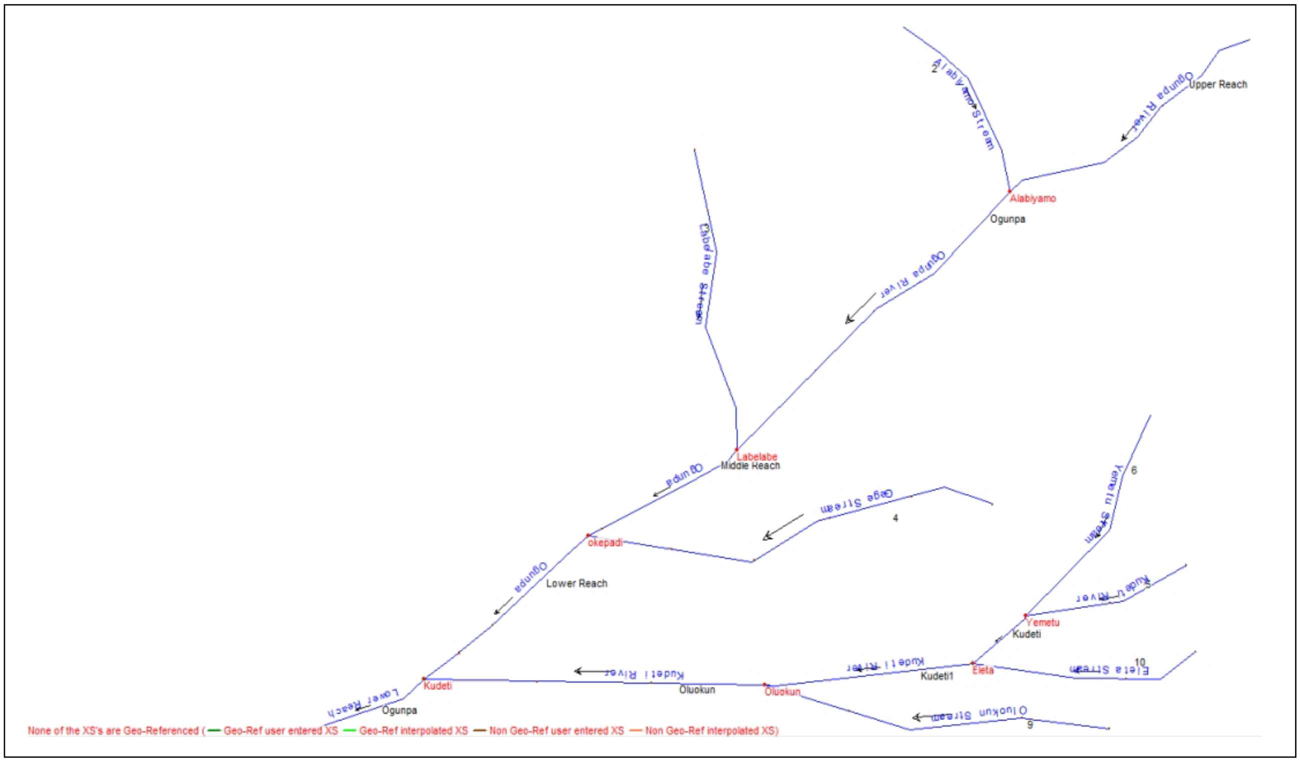

Figure 2. Ogunpa River system schematic.

defining the start and end of the reach. It is customary to draw a reach with several points that would follow along the main channel as in the upper, middle and lower Ogunpa. After the river system schematic has been completed the next step is the development of the river cross section.

Channel Geometric Data Entry

The river cross section platform is designated by the geometric data dialogue box. Each strategic point and joint is entered into the computer program to derive the geometric boundary of the stream (Ogunpa River). The cross sections are located at relatively short intervals along the stream and help to characterize the flow carrying capacity of the stream end to its adjacent plain (Figure 3).

Steady Flow Data and Profiles Entry

Once the geometric boundaries of the river have been determined, the steady flow data is then entered into the HEC-RAS system in order to derive the steady water surface profile. For this specific case study, the 50-year and 100-year profiles were used (Figure 4).

RESULTS AND DISCUSSION

The computation of the steady flow surface profile from the HEC-RAS modeling solution allowed for the determine of:- Channel Geometry, Flow Profile, Flow Volume, and Flow Velocity of the Ogunpa River, each of which is shown in Figure 5.

Figures 5(a) through 5(e) illustrate the various channel-shape patterns of the Ogunpa River as one move downstream. Figures 5(a) and 5(b) represent the channel geometries of the upper course of the Ogunpa, while 5(c) through 5(e) represents those of the middle and lower courses.

For the upper course of the river, the water surface profile did not exceed the bank of the channel, and there was no indication of flooding in the area. For the middle and lower course

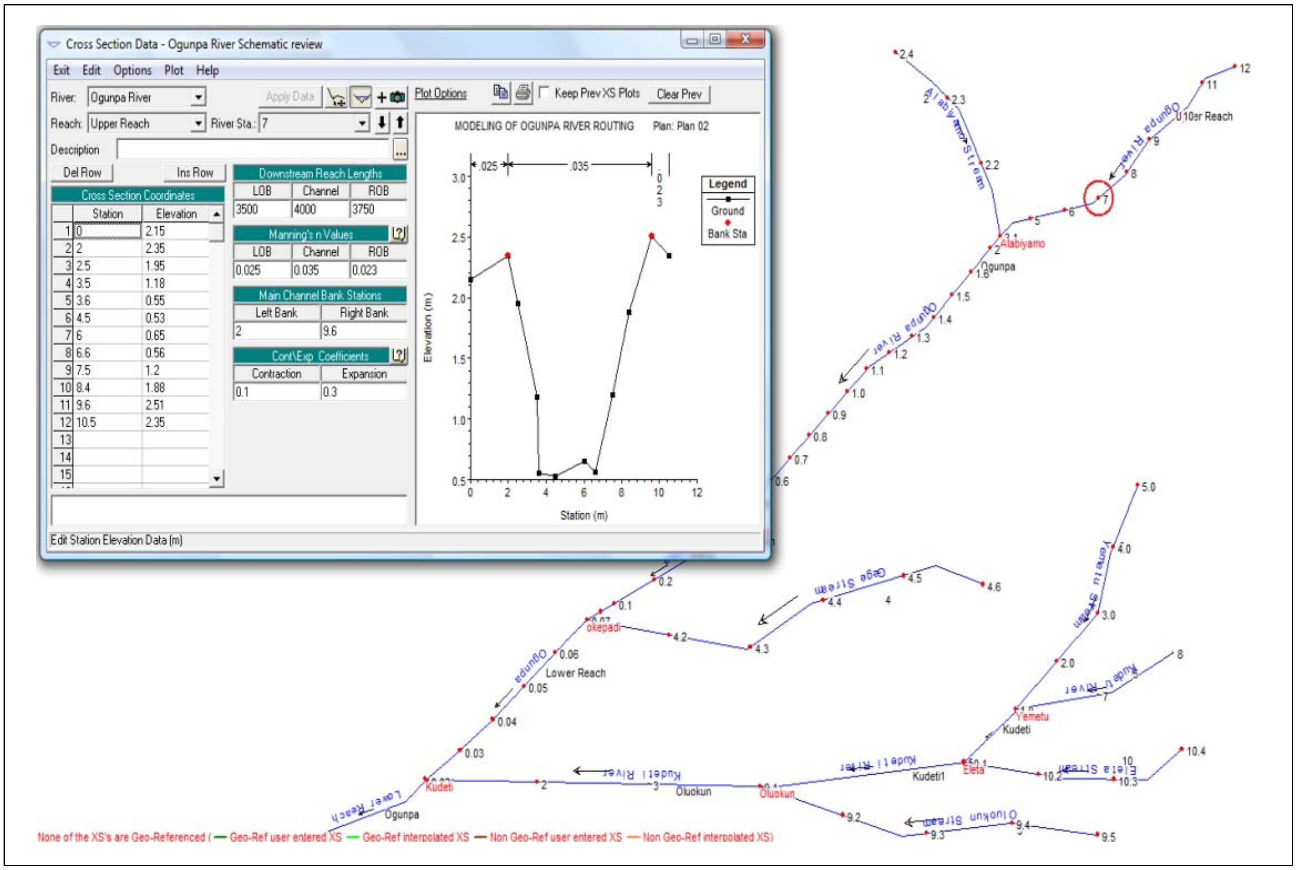

Figure 3. Channel geometry data entry.

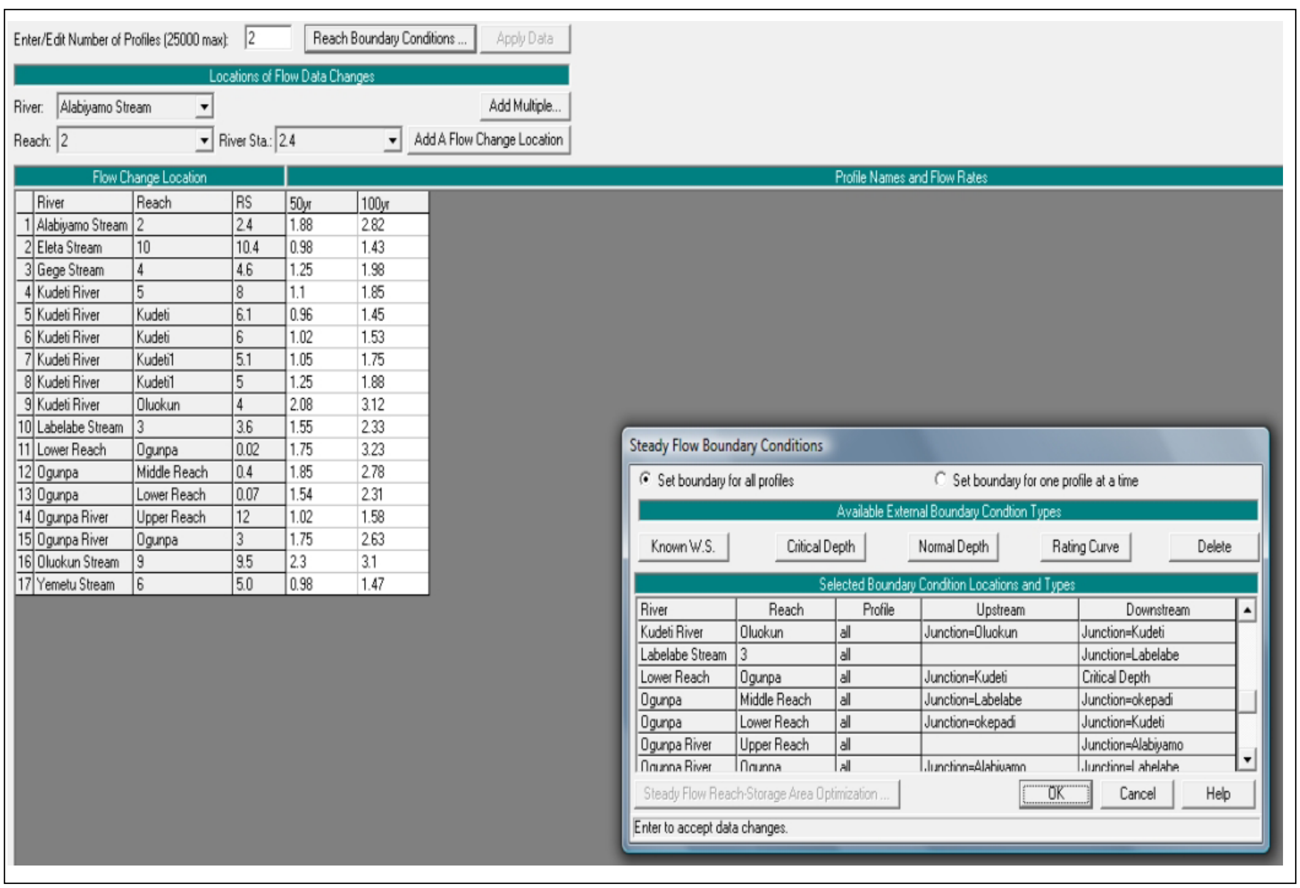

Figure 3. Channel geometry data entry.

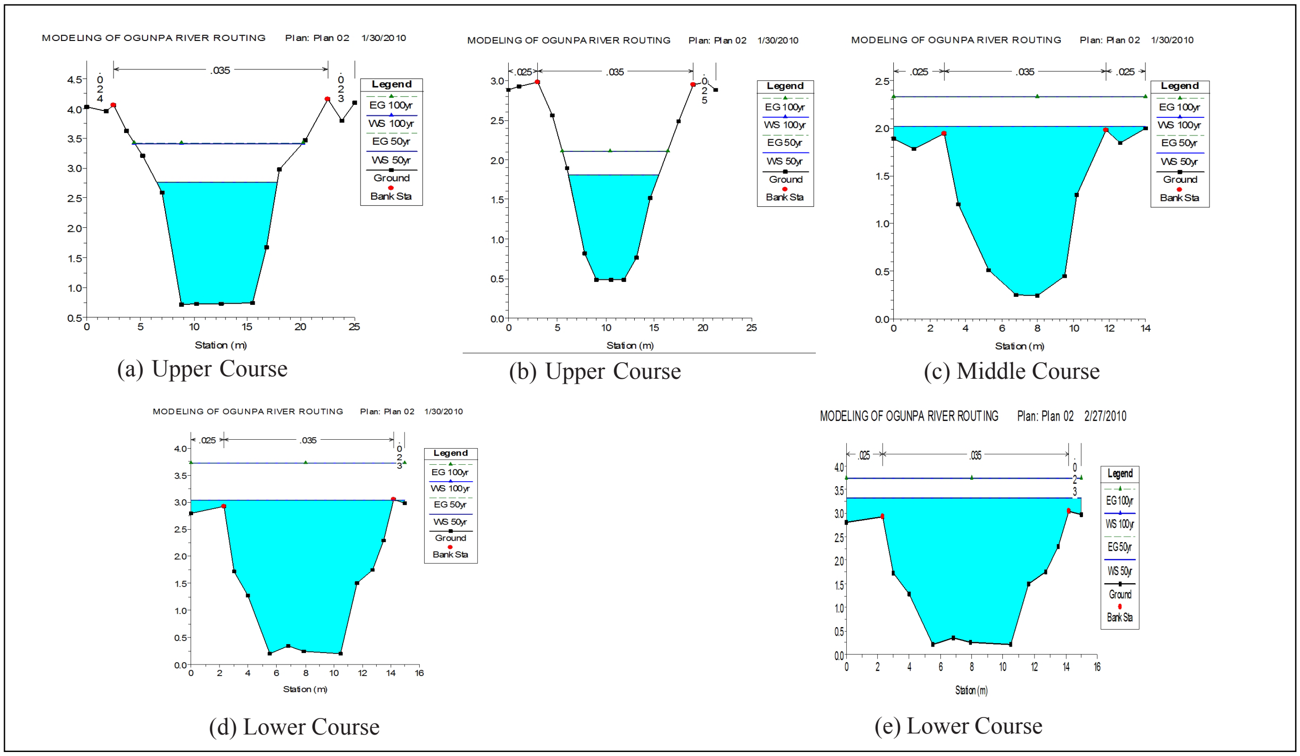

Figure 5. Simulated Channel Geometry of Ogunpa River.

regions, however, the water surface profile did exceed the bank of the channel, making these areas a frequent flood zone. Despite the topographical irregularities in the river bed slope (which is due to the impervious nature of Ibadan's geological surface), it was found that the Ogunpa's water profile increases as the water flows downstream. The water profile increases as one move downstream along the length of the river. The highest water elevations were measured at the lower course, which is due to the compilation and build-up of refuse in this particular region, as shown in Figure 6.

Because the water volume is directly proportional to the length of the river as shown in Figures 7a-c, the highest volumes of water should have been observed at the lower course of the river. However, this was not found to be the case, as the modeling in Figure 7c illustrates. The volume of water at the lower course of the river was supposed to be the highest but a contrary result was found (shown in Figure 7c). This might be as a result of the 'ponding' effect experienced in this region due to accumulation of refuse along the river course.

The flow velocity simulation did not have a normal distribution especially in the lower course of the river. In Figures 8b and 8c, the flow velocity tended towards zero. This significantly affected the water elevation profile within the area and created the aforementioned 'ponding' effect. The lower course region was also characterized by severe water discoloration, foul odors, and an abnormally high mosquito population. Previous research by Sangodoyin (1996, 2002) had identified this region as the most vulnerable to flooding, and HEC-RAS modeling performed during this study confirmed the finding.

Even if the Ogunpa channelization project is successfully completed, flooding will continue to occur if Oyo State does not enforce proper waste management. Waste management policies should be enforced by the appropriate environmental agencies of the Oyo state government. Possible solutions could be excavation of the Ogunpa flood plain encroachment and relocation of

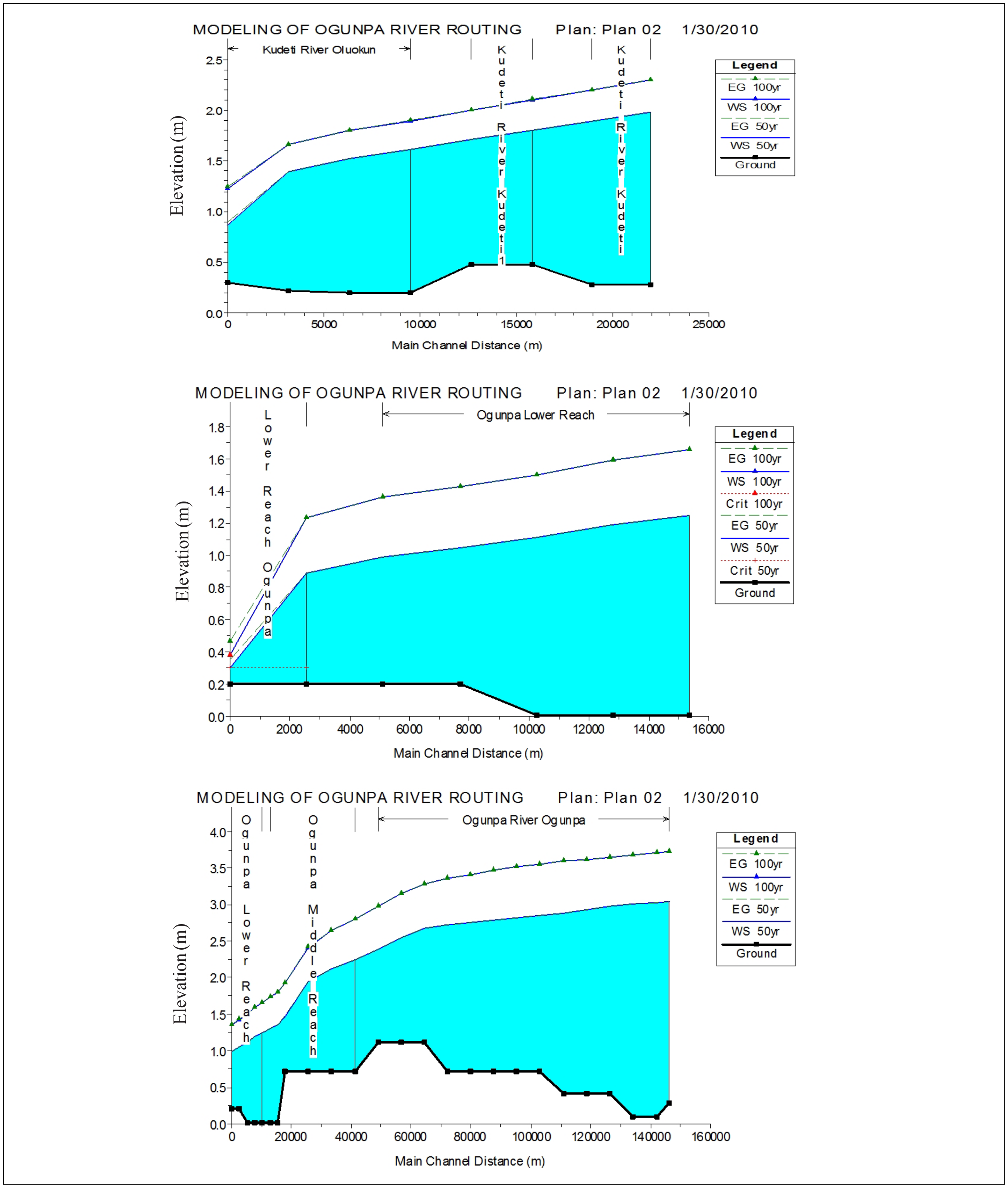

Figure 6. Simulated water elevation profile of Ogunpa River.

existing flood plain occupants. Installation of flood control devices such as flumes, weirs and dykes should be explored by the State Government.

CONCLUSION

Poor waste management combined with an inadequate drainage system (nonexistent water infrastructure) is a key factor in the frequent flooding of the Ogunpa River. However, the climate

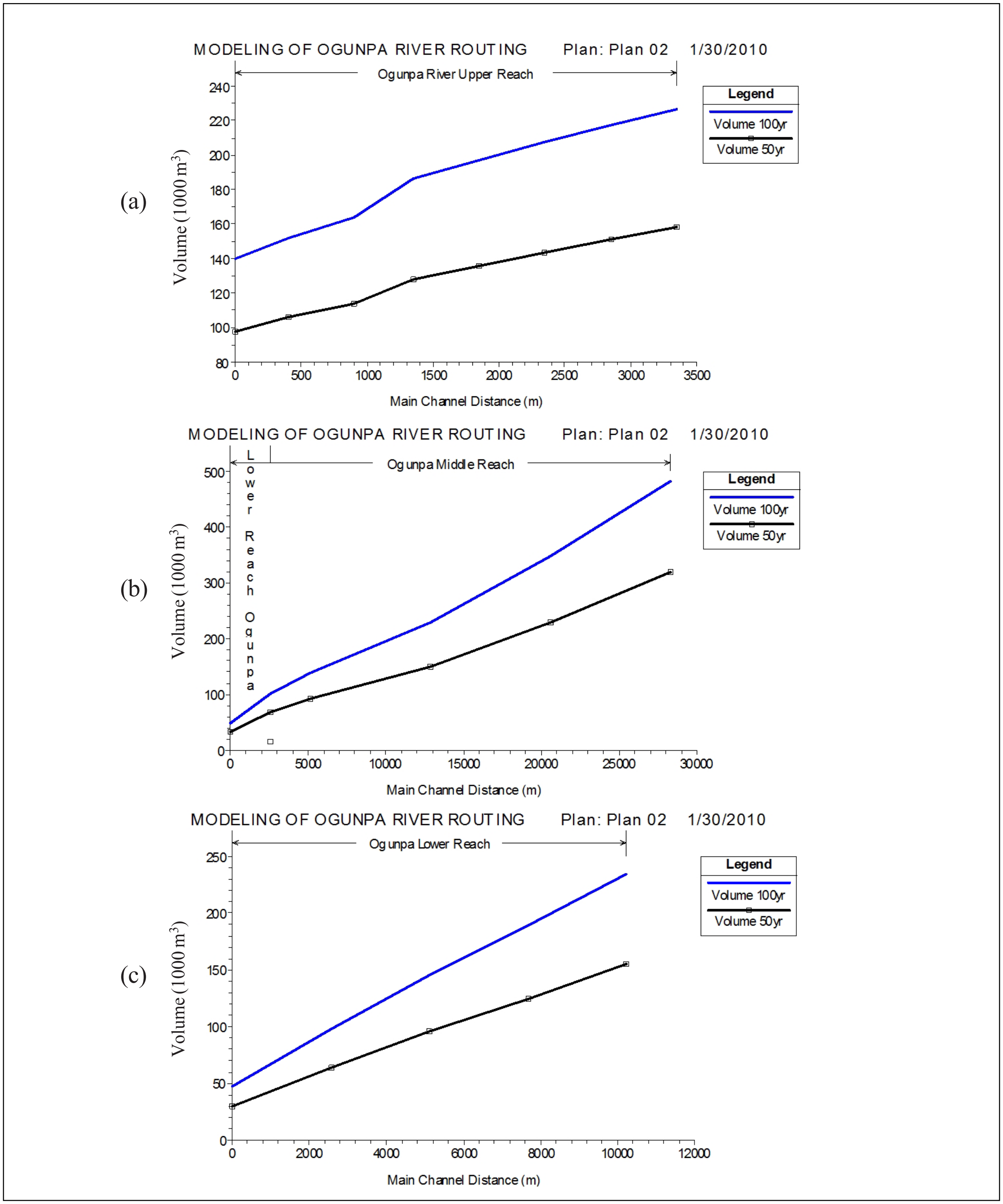

Figure 7. Simulated flow volume of the Ogunpa River.

of this region cannot be overlooked as it greatly exacerbates the high probability of flooding in the region. Ibadan is located along the tropical belt of Nigeria and as a result experiences an annual rainy season that lasts close to ten months, with the highest-intensity rainfalls occurring from the end of June to early September. The observance of lower-course flooding is attributable to the fact that the high discharge and water volume that travel downstream are eventually halted by the zero-trending velocities at the end of the channel. This, in combination with refuse accumulation, results

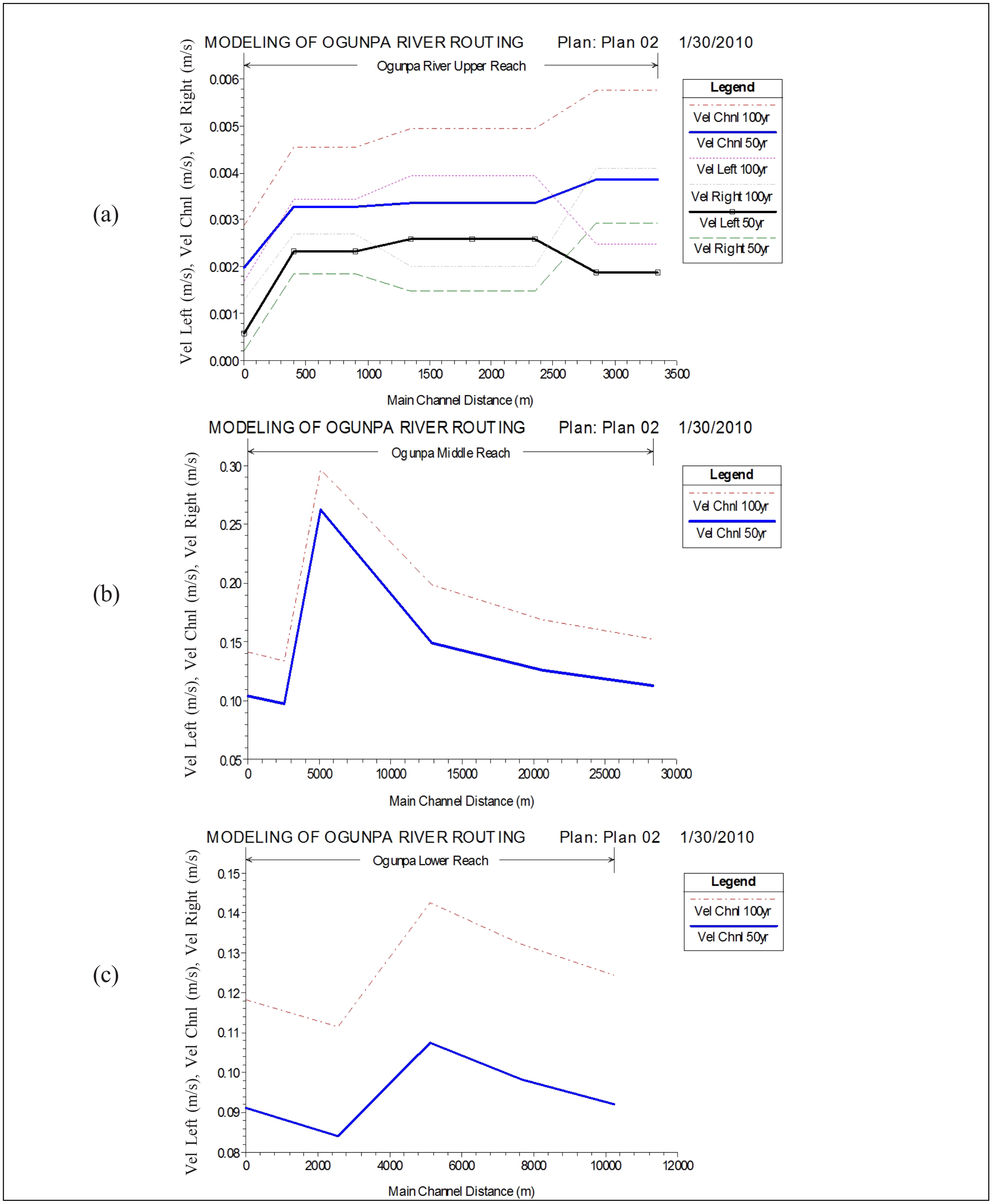

Figure 8. Simulated flow velocity of the Ogunpa River.

in water surface profiles that exceed the banks of the river. The HEC-RAS model has been able to identify those particular sections of the Ogunpa river course that are susceptible to high water elevation levels and head, both of which are significant indicators/precursors to flooding events. If a proper waste disposal system is not implemented in conjunction with the channelization project, there will be little likelihood of success for the latter.

ACKNOWLEDGMENTS

The authors thank Dr. Olumuyiwa Ojo of Tshwane University of Technology in South Africa and Dr. Bogdan Ozga-Zielinski of the Polish institute of Meteorology and Water Management for reviewing this manuscript.

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